Black Carbon Research in NOAA/ESRL Chemical Sciences Division

Black carbon contributes to global warming and is implicated in the rapid melting of glaciers and sea ice. Further, black carbon is a health hazard. Black carbon has a very short residence time in the atmosphere. Reductions in its emissions could therefore provide rapid relief for the climate system and human health. There is an immediate and important need to understand and quantify the role and impacts of black carbon and provide information necessary for decision making.

CSD black carbon research

The Chemical Sciences Division has state-of-the-art instrumentation and world-leading capabilities in analysis of sources, transformations, and properties of black carbon in the atmosphere and the effects of black carbon on climate and air quality. Collaborations and cooperation with other NOAA laboratories such as PMEL, GFDL, and ESRL-GMD, as well as National Environmental Satellite, Data, and Information Service's satellite data, provide an unprecedented capability in NOAA to quantify the role of black carbon on the Earth System. Collaborations with other agencies and organizations enable a complete capability to provide needed information.

The NOAA P3 investigating light absorbing haze over Brooks Range in Alaska. Photo courtesy of Dan Lack.

Measurements Capabilities at ESRL/CSD:

CSD has developed a suite of instruments to fully characterize the role of black carbon in the atmosphere by measuring single-particle black carbon mass and coatings, optical properties such as bulk absorption and single scattering albedo, chemical characteristics, and the distribution of absorption among different particles. These are custom or customized commercial instruments with capabilities that are unmatched anywhere.

- Photoacoustic aerosol absorption with a matched cavity ringdown to obtain single scattering albedo. These instruments operate at three wavelengths (405, 532, and 664 nm) to understand the wavelength dependence of the light absorption. They can measure the change in absorption and extinction with relative humidity. They have much better sensitivity and immunity from artifacts than instruments that rely on the darkening of filters.

- The NOAA Single Particle Soot Photometer (SP2) measures the refractory black carbon mass of individual particles as well as their coatings, which enhance light absorption by the black-carbon content. Combined with solar radiative flux measurements, the SP2 mass determinations can be used to estimate heating rates in ambient air samples.

- The single particle albedo (ASTER) instrument measures how light absorption varies from particle to particle. Typically, almost all of the light absorption comes from fewer than 20% of the particles. The ASTER instrument is the first to measure light absorption from single particles, allowing it to measure light absorption by non-carbon species such as mineral dust.

- Laboratory calibration and aerosol instrument intercomparison studies have provided a more fundamental understanding of the enhancement of light absorption by coatings. The response of the widely used TSI nephelometer to absorbing particles has been modeled and measured. There have been laboratory and field comparisons showing important limitations to the filter absorption (PSAP) data used in monitoring networks.

- Laboratory studies of chemical transformation of atmospheric gases on soot surfaces are studied using soot samples that are either from real-world sources or surrogates for real atmospheric soot. Such measurements of the loss of chemicals and formation of other chemicals enables an assessment of the impact of soot on the atmospheric composition. Further, these studies also characterize how soot itself is modified (aged) by exposure to atmospheric constituents and how their properties change.

Current Major Study Areas

Field investigations:

Frequent and widespread measurements from aircraft, ships, and ground sites are giving a better picture of the distribution of black carbon aerosol in the atmosphere.

- Continuing SP2 aircraft measurements aboard the NOAA WP3, the NCAR GV, and the NASA WB-57 aircraft have provided black carbon data from 200 feet over the Arctic Ocean to 60,000 feet over the Equator. These data are helping to reduce the uncertainty (factors of 10 to even 100) in model predictions of the vertical profiles of black carbon in the remote troposphere and lower stratosphere.
- The first measurements of black carbon emissions from a significant number of ships have provided new insight into an important global source. The emission factors of black carbon from urban areas and wildfires have also been measured. Analysis of data from the Pearl River region in China will provide understanding of sources in a highly polluted area.
- We have made pioneering measurements of how dust absorbs more light at high relative humidity. The change in absorption cannot be modeled with uniform particles, as often assumed in satellite retrievals. New instrument capabilities will allow these measurements to be made routinely in future field missions.
- Studies of the formation of organic aerosols and the coatings on black carbon particles are providing insight into processes that enhance light absorption beyond that from bare carbon particles.

Modeling and large-scale analyses:

To understand the national and global implications requires larger scale analyses than individual field studies. The following analysis activities involving black carbon are underway.

- CSD scientists are co-leading an international effort to develop an assessment of the climate effects of black carbon and the potential for mitigation to reduce the climate impact.
- Intercomparisons of black carbon measurements in the Arctic and remote Pacific regions are being conducted with the Aerocom suite of global aerosol models.
- Cloud modeling studies are looking at the effects of black carbon on cloud cover and reflectance. Processed black carbon particles may act as cloud condensation nuclei and increase cloud reflectance. However, under significant black carbon loadings, the reduction in surface radiation results in reduced surface forcing, atmospheric stabilization, and reduced cloud reflectance. The vertical distribution of the absorbing aerosol is also of importance. For example, black carbon can enhance the thickness and reflectance of a cloud layer if it is present above the cloud and the heating of the air there reduces entrainment of dry air into the cloud.
- Analysis of ground network data has shown that black carbon over wide areas of the US has a substantial weekly cycle. This verifies that diesel vehicles, which are used less on Saturdays and Sundays, are a major source of black carbon.

Arctic studies:

The Arctic is an area with rapid climate change, where soot in air as well as on ice have unique roles that lead to rapid ice melt, and the 2008 International Polar Year has focused research on the Arctic. CSD is placing a special emphasis on the effects of black carbon on Arctic climate.

- The ARCPAC mission has shown the importance of distant biomass burning to Arctic haze. There is a black carbon source associated with these fire emissions. Analysis of the ARCPAC data has provided direct evidence of the surface deposition of black carbon in the remote Arctic where it can reduce the albedo of snow and accelerate snow melt.
- The data obtained on black carbon emissions from shipping are being used in a model of the impact of ship emissions from future commercial shipping through the Arctic.
- Special emphasis is being placed on the Arctic in the comparison of black carbon measurements with global model results.
- The radiative effects of airborne black carbon above the bright sea-ice and snow surface of the Arctic is being evaluated using radiative transfer models constrained by the observations.
- Photoacoustic and ringdown instruments from NOAA CSD measured the albedo of aerosol particles in the Arctic marine atmosphere during the ICEALOT cruise.

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Future plans:

Our near-term plans for black carbon focus on the CalNex mission in southern California.

- Measuring emission factors of black carbon from various sources using instrumentation on both the NOAA P3 aircraft and research vessels. The inclusion of both gas-phase and aerosol measurements in the large payloads makes source attribution possible.
- Performing further field comparisons between the photoacoustic, PSAP, and SP2 techniques to improve accuracy and interchangeability.

Near-term plans also include further calibrations in cooperation with Boston College as well as continuing measurements of the global distribution of black carbon on the NCAR GV aircraft.

Our longer-term plans include:

- Identification and quantification of black carbon sources.
- Measurements of light-absorbing aerosols, such as dust and heavily coated black carbon, in highly polluted areas and other difficult environments. Potential applications include pollution in India and East Asia and the effect of Saharan dust on tropical storm development.
- Future comparisons of data with global models as well as other ways of bounding large-scale climate effects of black carbon.
- Future modeling of the effects of black carbon on clouds, especially changes in mesoscale circulations.

Payoffs:

√ Identified sources of black carbon with quantified strengths and uncertainties needed for policy decisions.

√ Better understanding of the sources, transformations, and sinks of black carbon in the atmosphere to enable characterization of the impacts of black carbon on climate.

√ Better ability to predict the climate impact of policies that control black carbon emissions.